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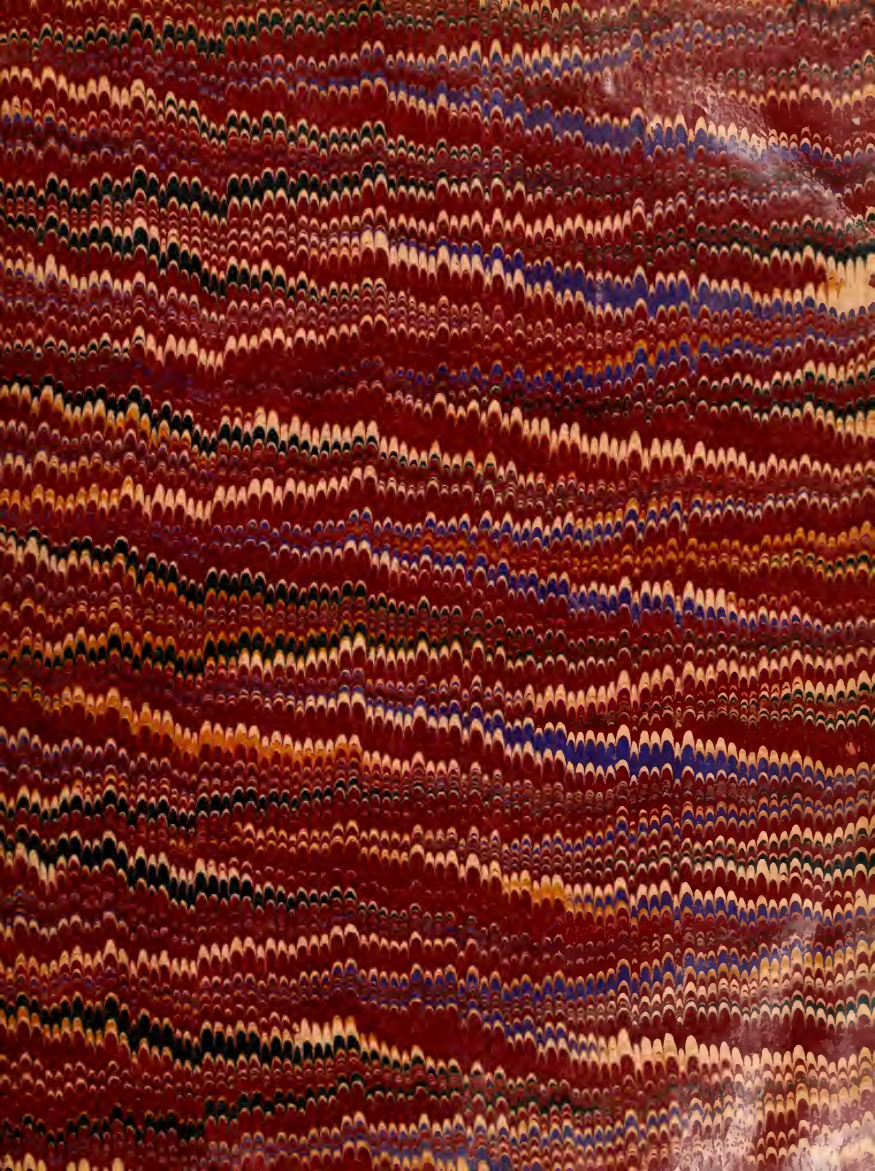

Middlekauff,
George Wiles
1903
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Measurements of Certain Wave-lengths in the Spark-Spectra of Iron and Titanium, together with a Study of the Possible Influence of Capacity and Self Induction in the Spark Circuit.

DISSERTATION

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DOCTOR OF PHILOSOPHY.

BY

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INTRODUCTION.

In all line-of-sight work the comparison spectrum is invariably that of the spark. For this reason it is a matter of importance to know whether or not the wave-lengths of the spark spectrum remain constant under varying external conditions of capacity, self induction, etc. Although considerable experimenting has been done on this subject during the last few years, yet there is a diversity of opinion among observers and so the question cannot be considered as settled. In view of this fact, Professor Ames suggested to the writer that an investigation along this line, with the facilities offered in this laboratory, would be of interest.

The iron spectrum was selected as the subject of study, and the work was undertaken with two principal objects in view; namely, 1, to produce the spectrum under the greatest possible variations in capacity and self induction and find the effect, if any, upon the wave-lengths of the lines; and 2, to make accurate measurement of the lines in the spark spectrum between 3850 and 4600 the region utilized by line-of-sight observers; and, at the same time, note differences between arc and spark lines.

[illegible]

I. Effect of Capacity and Self Induction upon Wave-length.

Historical Review.

It has been observed by Hemsalech*, Schenck**, and others, that when small amounts of self induction were introduced into the circuit of a condensed spark discharge, there was at once a complete extinction of all the air lines from the spark spectrum, and at the same time a narrowing of all the metallic lines. As the self induction was increased. certain characteristic spark lines, called "short lines" , disappeared while certain others, called "long lines", being also present in the arc, remained visible or increased in intensity. There was also a third class which were absent in the ordinary condenser spark, being present in the arc, but which appeared on introducing self induction into the circuit.

Another effect observed in the case of self induction was that as it was increased there was at the same time an increase in the temperature of the electrodes, and a decrease in the frequency of the spark; thus its tendency was to convert the spark into an arc.

The effect of the introduction of capacity, or of its

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* Comptes Rendus; 129, p.5, 1899; J. de Phys. Dec. 1899.
** Astrophysical Journal; 14, p. 116, 1901.

1. Effect of Capacity and Self Inductance upon Wave-length.

Theoretical Portion.

In the theory advanced in Chapter II, Equation (1), viz.:-

$$\lambda = 2\pi\sqrt{LC}$$

may be made a complete definition of all the oscillations which the system is capable of producing, and at the same time a measure of the capacity and self inductance of the system. Since the capacity and self inductance of all the oscillators used in this investigation were constant, the wave-length of the oscillations must also be constant. As the coil inductance was constant throughout the experiments, variation of wave-length could be produced only by variation of capacity. This was accomplished by introducing into the circuit a tube containing water, which could be raised or lowered in the tube, producing variable capacities of increasing or decreasing magnitude. There was also a fixed sphere which was introduced in the circuit when short waves were desired. The wave-length of the oscillations was then measured by the Lecher wire method.

The effect of the introduction of capacity, or of the

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* Equation (1), p. 7.

increase was, of course, the opposite of the effect of self induction.

But the point with which we are particularly concerned here is the effect of capacity and self induction upon the wave-length of the lines. Exner and Haschek*, in the course of their measurements of the ultra-violet spark spectrum of the elements, observed that in many instances the wave-lengths of lines in the spark spectrum differed considerably from the wave lengths of the corresponding lines in the arc, the difference being often as much as 0.5 of an Ångström unit. They considered this difference as due to pressure in the spark, and with data taken from the tables of Humphreys and Mohler**, they estimated the pressure in the spark to be from 24 to 30 atmospheres.

Then Haschek and Mache***, in order to make direct measurements of this assumed pressure, placed a spark in an air-tight vessel filled with air and furnished with a manometer. On discharging the spark, they observed a sudden rise in the manometer and interpreted it as a manifestation of a pressure in the spark. However, the value they thus obtained was far greater than the value of the pressure calculated from the difference in wave-length between arc and spark lines.

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* Sitz. der Kais. Akad. der Wiss. in Wien, 1897 et seq.
** Astrophysical Journal, 1896 and 1897.
*** Sitz. de Kais. Akad. der Wiss. in Wien, 1898.

" Cite. see Cite. Cite. Cite.

They * found also that as they increased the amount of capacity across the discharge circuit the effect was increased to a maximum and then decreased. The potential was furnished by a powerful transformer.

Then Mohler**, using an induction coil and a Rowland grating, found that with an increase of capacity there was an increase in the shift of the lines which seemed to approach a maximum value; but the calculated pressures obtained were, by no means as great as those found by Haschek and Mache.

In response to Mohler's results, Haschek and Mache*** claim that the former's work is but a confirmation of their own, the difference in value being due to the difference in energy produced by a transformer and an induction coil respectively.

Contrary to the results of the above observers Eder and Valenta****, on investigating some of the lines in which Exner and Haschek believed they had found an increase in wave-length due to capacity, obtained photographs which indicated no change whatever.

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* Astrophysical Journal; 9, p. 351, 1899.
** " " 10, p.204.
*** " " 12, p. 50, 1900.
**** Kayser; "Handbuch der Spectroscopie", Vol. II, p. 308.

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* Interpol Journal, p. 211, 2020.
** " " " " 10, p. 204.
*** Interpol "Handbook for Counterfeiters", Vol. II, p. 101.

Haschek* states that in many instances lines which in the spark were increased in wave length by equal amounts, were increased by unequal amounts in the arc under pressure, and conversely; also that even in the spectrum of the same element, the wave-lengths of the lines were increased by unequal amounts, indicating that other influences beside pressure were making themselves felt; and hence the pressure in the spark, if it be a reality, cannot be determined directly from any one line of the spectrum.

Haschek** observed also that there were increases in wave-length produced by increasing the amount of luminous vapor in the spark. This, however, is contrary to the results of Humphreys and Mohler*** who found that, in the case of the arc, only pressure and not vapor caused an increase in wave-length of the lines.

Wilsing****, with a strongly condensed spark placed under water, found that a very intense continuous spectrum was found, crossed, as in the case of iron, by numerous pairs of lines, consisting of a bright and a dark line, the former being considerably shifted toward the red, while the

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* Astrophysical Journal, 14, p. 187, 1901.
** " " 14, p. 187, 1901.
*** " " 3, 114-137, 1896.
**** " " 10, p. 116, 1899.

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Because" states that it must sometimes first check it is true before it can be known to be true. Logic, of course, also includes inferences of impossibility and of probability, and inferences by analogy, which in the end rather resemble, and sometimes, alas, fall even in the opinion of the same writers, into the main-length of the lines here discussed in modern logic; but these are the simplest and most basic.

Truths" assessed also that these were discussed in many and own line of the question.

Truths" assessed also that these were discussed in many-length produced to illustrate the extent of impossibility in the right. That, however, is obtained it its reader. Logic of Thoughts and Objects"*** else. Final that is the only world of the more reply treasure and not rather referred as inference to many-length of the lines.

All-and****, with a strongly consonant among pieces in many, found that a very- improve mathematic theories, and then found, however, as in the case of laws, by consonant part of times, possibility of a twelfth and a part time. Inference being investigation- military itself the red, while its

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*. Rather-Objects Logic", 19, p. 384, 1967.
**. " " 19, p. 384, 1967.
***. " " 19, (in-)27, 1974.
****. " " 20, p. 117, 1967.

latter was shifted in the same direction in only a few instances. Besides these pairs there were isolated bright lines which exhibited an appreciable displacement toward the red.

This investigation was repeated later by Hale* and Lockyer**, working at the same time but independently. Hale found that with the use of an alternating current and an air gap in circuit the spark under water gave a spectrum reversed in some parts, a phenomenan which in the case of salt solutions extended throughout the spectrum; and further in certain groups there were shifts and changes in relative intensity of the lines. With the use of a Wehnelt interrupter or an induction apparatus the reversals did not occur.

Lockyer employed a large Ruhmkorff coil and obtained a spectrum with bright and self reversed lines. Further there was a broadening and a shift of the bright lines towards the red. He examined the spectra of iron and several other metals and divided the observed lines into three classes: 1. Broadened bright lines, 2, broadened bright lines with central absorption, and 3, broadened bright lines

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* Astrophysical Journal 15, p. 132, 1902.
** " " 15, p. 190, 1902;
Pro. Roy. Soc. 70, p. 31, 1902.

with nonsymmetrical absorption (maximum of emission towards the red). He found that in certain cases the one component of the self reversed line was either much weaker than the other or was absent entirely, and hence the bright line was in a position greatly displaced towards the red.

Konen*, with a large induction coil and capacity, found that with the spark under various liquids, in general, the lines were either all bright or all dark. In regard to intensity changes, his work confirmed that of Hale and Lockyer. In reference to Lockyer's classification, Konen** states that in it Lockyer was dealing apparently with self reversed lines only. He, himself, found many lines which were undoubtedly not self reversed, but were dark upon a continuous background. He found also lines broadened to one side without a trace of absorption, shifted bright and dark lines, and finally between shifted lines were others which exhibited no shift at all.

Hale and Kent***, working together, found that with the spark placed in liquids a decrease in self induction in the discharge circuit changed the spectrum from one consisting almost wholly of bright lines to a spectrum consisting mostly of dark lines; at the same time "the bright lines

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. Drude's Annalen, (4), 9 p. 775, 1902.

.. " " 9 p. 776, 1902.

... Astrophysical Journal, 17, p. 155, 1903.

. Dunbar's Invasion, (1), p. 178, [illegible].

.. " " p. 181, [illegible].

... Unidentified Document, [illegible], [illegible].

move gradually toward the red, while the absorption lines, which begin to appear in the earliest stages, may at first have some apparent shift toward the violet, though later they may be displaced one or two hundredths of a tenth-meter toward the red, rarely more".

These results taken together with those of Mohler*, who observed that capacity shifts the spark lines toward the red, would indicate that capacity and self induction act counter to each other in shifting the lines.

Finally Kent** alone repeated some of Exner and Haschek's work, and observed that in the case of titanium, there was a shift due to capacity, but that it did not amount to more than 0.04 of an Angstrom unit for lines in which Exner and Haschek observed as much as 0.13 of an Ångstrom unit.

The Present Investigation.

Apparatus.

The grating employed in this investigation was a twenty-one and a half foot concave Rowland grating with 20000 lines to the inch, mounted as described by Professor Ames in the Philosophical Magazine, 1889, p. 369, and being in all the same instrument used by Humphreys and Mohler in their work

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* Astrophysical Journal, 9, p. 351, 1901.
** " " 14, 201, 1900.

on pressure shift. For the purpose of comparison of spectra, the camera carries a shutter consisting of a long brass plate, capable of revolution around a horizontal axis and having throughout its length a longitudinal opening of a width equal to the thickness of the plate; so that when the shutter is in a vertical position the photographic plate is exposed along a strip extending over the whole length of the plate and over a width equal to the thickness of the shutter. When the shutter is turned horizontal, the central strip is covered and the remainder of the plate above and below the strip is exposed. To avoid any jarring of the camera when the shutter was turned between comparison spectra, the shutter was detached from the camera and supported by two iron clamp stands which stood upon the floor. As the beam on which the camera rested was supported by the walls of the building, there could then be no possible jarring due to motion of the shutter. In addition to the shutter already described, there were three others placed a few inches in front of it. These were each about seven inches long, were placed end to end, and were capable of turning about the same horizontal axis. They were also supported by the clamp stands mentioned above. When all three were in a vertical position, no light from the grating could strike the photographic plate. When the left hand one, say, was in a horizontal position and the other two vertical, only the left

end of the plate could be exposed, no matter how the first shutter with the opening in it was turned. With the middle one horizontal and the end one vertical, only the middle portion of the plate could be exposed, etc. These four shutters were operated by means of cords leading to a point near the slit. This was done so that the operator need not move from a fixed position during the exposure of the plate and thus avoid possible shaking of the apparatus due to his walking over the floor.

The spark was produced by a 50-volt alternating current of about 25 amperes with a frequency of 133 cycles per second. After being stepped up to about 600 volts, it was passed through a transformer, known as a "Rowland coil," which raised the potential sufficiently to produce a spark of about two centimeters in length. For the first 25 photographs the Rowland coil was made up of a primary of 8 layers of 150 turns each of number 12 insulated wire, and a secondary of about 100 layers of about 180 turns each of number 25 copper wire. This secondary broke down at this point, and a new one was made to take its place. The new coil consisted of 98 layers of 164 turns each, being in all 30 pounds, of number 25 double cotton covered copper wire. The winding was done dry with simply a sheet of paper between the adjoining layers. To further insulate the wires, the coil, still in the brass

form on which it was wound, was boiled 12 hours in beeswax under reduced pressure. The potential furnished by this coil was slightly less than that of the old one .

The spark terminals were cylindrical rods of Norway iron, about 15 centimeters long and 8 mm. in diameter, turned down at the spark ends to the shape of a blunt lead pencil point. These points would wear down slightly during a long exposure, but care was taken to always turn them to the proper shape before each and every exposure. They were given this shape so that the spark would keep on the slit all the time of exposure and not jump about as it would with terminals more blunt and flat.

An auxiliary spark gap was tried in series with the main spark gap, but as there was no appreciable improvement in the spark, so far as could be noticed by the eye or ear, no photographs were taken with it in.

The arc for comparison spectra was produced by a 110-volt direct current of about 10 amperes. The arc terminals were also of Norway iron rods, these being about a centimeter in diameter.

Both the arc and spark lamps were placed (the arc nearer the slit) upon a platform which was movable upon two knife edges in a direction parallel to a line drawn through the centers of the slit and grating respectively. Stops were placed before and behind the platform at such a distance from it that when it was against one of them the arc was in focus,

and when it was against the other the spark was in focus; that is, in both cases the source of light was in precisely the same place at a distance of 130 centimeters from the slit.

The light was focussed upon the slit by means of a quartz condensing lens which was never disturbed during the exposure on any one given plate, so that all exposures would have the grating illuminated as near as possible the same. The spark gap was usually 8 or 9 mm. in length and its image on the slit about 6 mm. Care was taken to always have the image as symmetrical as possible with respect to the slit; but in many instances, however, especially with the self induction in circuit, the image during exposure passed through many unsymmetrical forms.

Immediately back of the slit was a card screen supported by a beam perfectly independent of the mounting of the grating. This screen was movable about a horizontal axis and could be raised or lowered from the slit without disturbing the rest of the apparatus.

The capacity consisted of plates of copper foil and glass surrounded with paraffin, and could be varied from 0.0085 to 0.0739 microfarad. The self induction consisted of three coils of number 10 copper wire, each one meter in length and having 106, 206 and 186 turns respectively,

the first and second being 8 centimeters and the third 15 centimeters in diameter. The second and third were mounted one within the other. Thus the self induction could be varied approximately from about 0.00007 to 0.0012 of a henry. The whole of the induction, or any part of it, could be thrown in or out of circuit without stoppingthe spark.

The plates used were Seeds' No. 27 and Cramer's Isochromatic, all cut to 1 1/4 by 19 inches, and were developed with a hydrochinon solution according to Jewell's formula*.

The time of exposure varied from 15 to 60 seconds for the arc, 3 to 10 minutes for the spark without self induction, and from 10 to 60 minutes for the spark with self induction.

All measurements on plates were made with the dividing engine which is fully described by Humphreys in the Astrophysical Journal, 6, p. 180, and also by the method described at the same place.

Method of Exposure.

One of the greatest difficulties encountered was the mechanical shift which appeared in greater or less degree upon nearly every plate. At first this was taken for a true shift; but as it occurred sometimes in one direction and at other times in the opposite direction, it was quite evident that it was due to some external cause, possibly to a jar

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* Astrophysical Journal 11, 240, 1900.

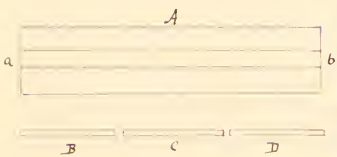
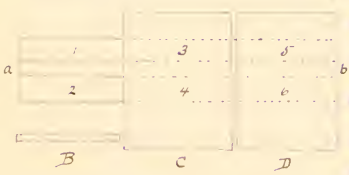
given the camera on turning the shutter which was at first attached to the camera. For this reason it was decided to detach the shutter from the camera entirely. Even then there was often a mechanical shift. This was due sometimes, at least, to a jarring of the building caused by heavy wagons passing on the street. But with the method of exposure described below, it was always possible to detect every such shift when it occurred, and correct for it.

So far as known to the writer, all observers on the shift of spark lines have used an arc spectrum for comparison and have photographed the two spectra on the same plate. This, of course, necessitated the change of light source and the possibility of error due to the two sources not being in turn at exactly the same point.

To avoid error from this source, the method adopted in the present investigation was to compare the spectra of the same spark under any two given external conditions. Since the capacity and self induction could be thrown in or out by means of switches, the spark was kept going from the beginning to the end of all exposing on any one plate.

The general plan of exposure will be understood from the following example. Suppose the plate is to be taken to test the effect of self induction. The spark is first tried with

and without self induction in series to see whether the image falls on the slit and whether the grating is properly illuminated in both instances. Having made any necessary adjustments, the self induction is thrown out and the shutter at the slit is turned down to keep the light from the spark off the grating until the photographic plate is adjusted in the camera. With the camera shutter A vertical and the other three, B, C, D, horizontal, the plate is ready to be exposed over the strip a b along its whole length. The shutter at the slit is now raised and the exposure begun. When the proper time for the exposure has expired, the shutters C, D, and A are turned in the order named, so that now the portions 1 and 2 of only the end section of the plate are exposed. When these are exposed as long as a b was, B is turned up and the self induction is thrown in circuit; after which the shutter C is let down to expose the portions 3 and 4. This exposure being finished,



C is turned up, the self induction is thrown out and the shutter D is let down, thus exposing 5 and 6 under external conditions identical with those under which the middle strip a b, and the sections 1 and 2 were exposed. Hence if no mechanical shift occurred during the exposure, the lines in 1 and 2, and 5 and 6 will be exactly in line with the corresponding lines in the section a b. Or, if the apparatus was disturbed during the exposure of 3 and 4, causing the lines in them to be shifted, the lines in 5 and 6 will be shifted an equal amount. If, however, the lines in both the end sections are perfectly in line with those in the strip a b, and those in 3 and 4 are not, we can be sure the difference is a true shift.

Results.

A large number of plates were taken by the method described above, to test for a shift due to self induction; and invariably it was found, so far as the accuracy of measurement permitted, that no shift ever occurred when the self-induction was thrown in circuit. The self induction spectrum was always photographed in the middle section, sometimes outside, at other times inside. The order in which the sections were taken was also varied, but in every case

the self induction spectrum was checked before and after its exposure by a spectrum without self induction and with the capacity the same.

In the following table is given an example of the general average of the plates. The capacity was about .0739 microfarad and the self induction in circuit about 0.0012 henry. It will be noticed that there is but a small variation in the amount of shift, and is the same in all three sections. In this particular case there must have been some disturbance about the time the camera shutter was turned.

Left Section		Middle Section.		Right Section.	
λ	shift*		shift	λ	shift
4045.97	.007	4132.23	.005	4383.71	.006
63.75	.006	43.59	.002	4404.91	.007
71.91	.004	4202.20	.006	15.29	.006
91.71	.003	50.94	.008		
		60.65	.011		
		71.92	.005		
		4308.07	.012		

* Due to mechanical causes.

A number of plates were also taken to compare the spectra of the spark with large and small capacities, the variations being made from 0.0085 to 0.0739 of a microfarad. In these the lines were, of course, quite broad; but within the limits of accuracy of measurements no sensible change in the position of the lines was observed.

A few plates were also taken of the titanium spectrum in the region observed by Kent.* The same variations were made in capacity and self induction as in the case of iron; but, as before, the shift, if any, was too small to be detected.

Hence the conclusion to be drawn from the present research is that, in the case of a spark discharge in air, there is no change produced in wave length by variations of capacity or self induction within the range specified.

A further conclusion which has been reached from a careful examination by means of a magnifying glass, of all the many photographs taken with the arc and spark spectra on the same plate, is, that so far as can be thus determined, there is no appreciable difference in wave-length between the arc and spark lines.

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* Astrophysical Journal 14, P. 201, 1901.

[illegible]

II. Measurement of Spectra.

Introduction.

Wave-lengths of the spark spectrum of iron have been made by Huggins, Thalen, Kirchhoff, Hartley & Adeney, Lockyer, and Liveing and Dewar*; but the most recent determinations are those of Exner & Haschek**, being a part of their great work on the Ultra-violet Spark Spectra of the Elements.

The last observers made all their measurements from plates taken in the first order spectrum of a 15-foot concave grating. Their method of measurement which was not entirely free from objections, was to project an enlarged image of their negatives upon a screen where it fell upon a scale of 5 mm. divisions from which they read off the wave-lengths. Considering these two facts it is reasonable to expect greater accuracy from measurements made with a carefully constructed dividing engine and upon plates taken in the second order spectrum of a 21-foot grating, as was the case with the wave-lengths given in the following table.

Since the results of the first part of this investigation indicate that there is no appreciable difference between the wave-lengths in the spectrum of the arc and those

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* Watts' "Index of Spectra" p. 57.
** Sitz. der Kais. Akad. der Wiss. in Wien. 1897 et seq.

II. Beginning of Service.

Introduction.

Three-fourths of the steady operation of time there [illegible] made by Tuesday, Thursday, Saturday a shower, [illegible] and Tuesday and Thursday, but the more recent determinations are those by Tuesday & Saturday**, being a part of their [illegible] work on the Cleveland-Detroit Special Service of the Standard.

The last discussion under all their [illegible] plates taken in the first order operations at a different [illegible] Their method of manipulation [illegible] Under the Time Relations, was to [illegible] Cleveland Time Relations, was to [illegible] Cleveland Time Relations, was to [illegible] Cleveland

in the spectrum of the spark in air, it would appear unnecessary to make further measurements of the spark spectrum, because the wave-lengths of the arc spectrum of iron have been so accurately determined by Rowland*, Kayser**, and Fabry & Perot***. It is of importance, however, to make a comparison between the relative intensities in the arc and spark, repsectively; and to note the lines peculiar to the spark alone. Further, accurate descriptive knowledge of spark spectra is of great importance in many astro-physical phenomena.

Apparatus.

The same grating was employed for this part of the investigation as was employed for the first. The dividing engine, to which reference was made before, was constructed by Professor Rowland and was used in his work on the Solar Spectrum. For plates taken in the second spectrum of a 21-foot grating, the scale reads approximately to Ångstrom units.

Method of Exposure.

As was stated before, the arc and spark lamps were on a movable platform. The spark spectrum was usually taken first;

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* Phil. Mag. 36, p. 49, 1893.
** Astro-physical Journal 13, p. 329, 1901.
*** " " 15, pp. 73 & 261, 1902.

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the shutter was turned by the cord, as described above, and then the platform, which was independent of the mounting of the grating, was carefully slipped back on the knife-edges under it, thus placing the arc in precisely the same place previously occupied by the spark. The quartz lens, which focussed the image on the slit, was, in the mean time, kept rigidly fixed.

Lines and Standards Chosen.

It was not the purpose, by any means, to measure all the spark lines, but only those between 3850 and 4600, the region used by line-of-sight observers; and even of those only the strongest were taken, except in regions where but few strong lines occur. There a few comparatively weak lines were selected and measured. Besides these, the table contains the characteristic lines of this part of the spectrum, i. e., lines appearing only in spark and not in the arc, and are marked "c" in the table.

The standards used were lines whose wave-lengths have been recently redetermined by Mr. L. F. Jewell, basing his measurements upon the original wave-lengths of Professor Rowland.

Corrections.

A calibration curve was drawn for each and every plate, with wave-lengths as abscissae and the difference between

readings and the arc standards as ordinates. From these curves the corrections for intermediate lines were read.

The mechanical shift was also determined and corrections were made for it.

Table of Wave-lengths.

In making the estimates of relative intensities between the arc and spark lines, the line 4045.969 was taken as the standard, and such plates were selected as had this line of the same intensity in the spark as in the arc. This intensity is marked 15 and corresponds approximately to Kayser's mark 10. The letter "r" indicates that the lines so marked are easily reversed.

Wave-lengths	Intensity & Character.		Wave-lengths	Intensity & Character.	
	Spark	Arc.		Spark	Arc.
3850.116	4	2 r	4022.022	1	1
56.518	5	2 r	45.969	15	15 r
60.052	8	2 r	63.751	12	12 r
65.675	3	2 r	71.908	10	10 r
72.642	3	2 r	4118.721	3	3
78.163	5	3 r	32.226	4	4
78.724	5	3 r	43.587	4	4
86.423	5	2 r	44.035	6	5
99.850	4	3 r	57.976	1	1
3903.089	4	3 r	75.806	1	0
20.399	4	2 r	81.924	3	3
28.065	4	2 r	87.219	3	3
30.438	4	2	87.981	3	3
48.925	0	1	91.613	2	2
56.830	1	1	99.266	6	6
69.406	8	6 r	4202.197	7	7
77.894	0	1	10.528	0	2
84.117	0	0	19.529	1	2
97.540	2	2	22.396	1	1
4005.400	8	8	27.000	2	4
14.691	1	1	33.330	1 c	

Wave-lengths	Intensity & Character.		Wave-lengths	Intensity & Character.	
	Spark	Arc		Spark	Arc.
4233.769	2	3	4404.913	12	12
36.100	3	4	15.287	10	10
47.600	1	3	22.733	0	1
50.287	3	4	27.476	1	2
50.940	4	4	30.778	0	1
60.648	6	7	42.499	1	3
71.318	4	6	43.353	1	2
71.918	7	7 r	47.890	2	4
82.560	3	4	59.296	1	3
94.280	3	4 r	61.831	0	2
4308.071	10	10 r	66.718	2	4
15.250	3	4	76.196	2	4
25.928	10	10 r	82.411	1	4
37.209	2	3	94.744	2	4
51.923	0 c		4520.810	0 c	
52.900	1	3	28.809	3	5
67.750	0	1	31.352	0	1
69.939	0	2	49.610	0 c	
76.094	1	2	84.000	0 c	
83.706	15	15 r			

In conclusion, the author takes pleasure in acknowledging his indebtedness to Professor Ames at whose suggestion this investigation was undertaken and under whose immediate supervision it was carried out. He wishes to thank Mr. L. E. Jewell for assistance in the selection and measurement of lines; and also Professor Wood for his interest and suggestions during the progress of the work.

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BIOGRAPHY.

George Wiles Middlekauff, son of H. D. and Lydia Ann (Wiles) Middlekauff, was born at Leitersburg, Maryland, June 5, 1869. After receiving his early education in the public schools of his native village, he entered Franklin and Marshall College in the Spring of 1888, pursuing a classical and scientific course, and graduated with the degree of A. B. in June 1891. Three years later he received the degree of A. M. from the same institution. During the year 1891-2, he was instructor of Mathematics in Palatinate College, Myerstown, Pa. The following year he spent in graduate work in the Electrical Engineering Department of Johns Hopkins University. From 1893 to 1899 he was engaged in teaching; one year, as principal of the Leitersburg Schools, and five years as instructor in the Waynesboro (Pa.) High School. In the fall of 1899, he again entered the graduate department of Johns Hopkins University, and pursued advanced work in Physics, Mathematics and Chemistry. The Summer of 1902 he spent in pursuing a course in Laboratory Arts in the University of Chicago. During the sessions of 1900-1 and 1902-3, he was the University Scholar in Physics in Johns Hopkins University; and during the Session of 1901-2 he was Student Assistant in the Physical Laboratory.

During his graduate work, he attended lectures by Professors J. S. Ames, R. W. Wood and W. J. A. Bliss in Physics; Professor L. Duncan and Dr. J. B. Whitehead, Jr. in Applied Electricity; Professors F. Franklin and L. S. Hulburt and Dr. A. Cohen in Mathematics; and Dr. E. Renouf in Chemistry.